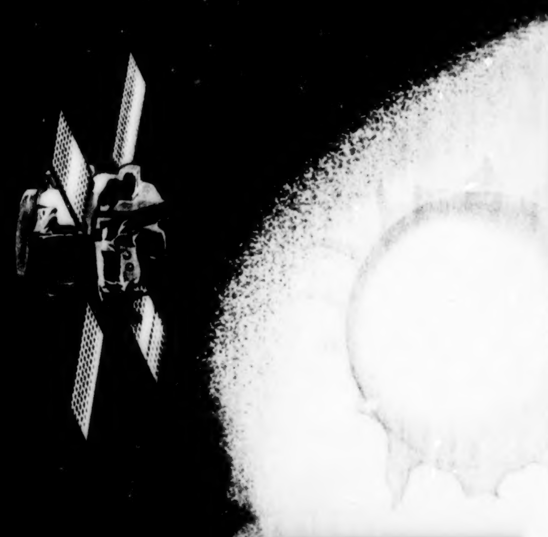
ADVANCED COMPOSITION EXPLORER



ACE

A C E

ACE Facts

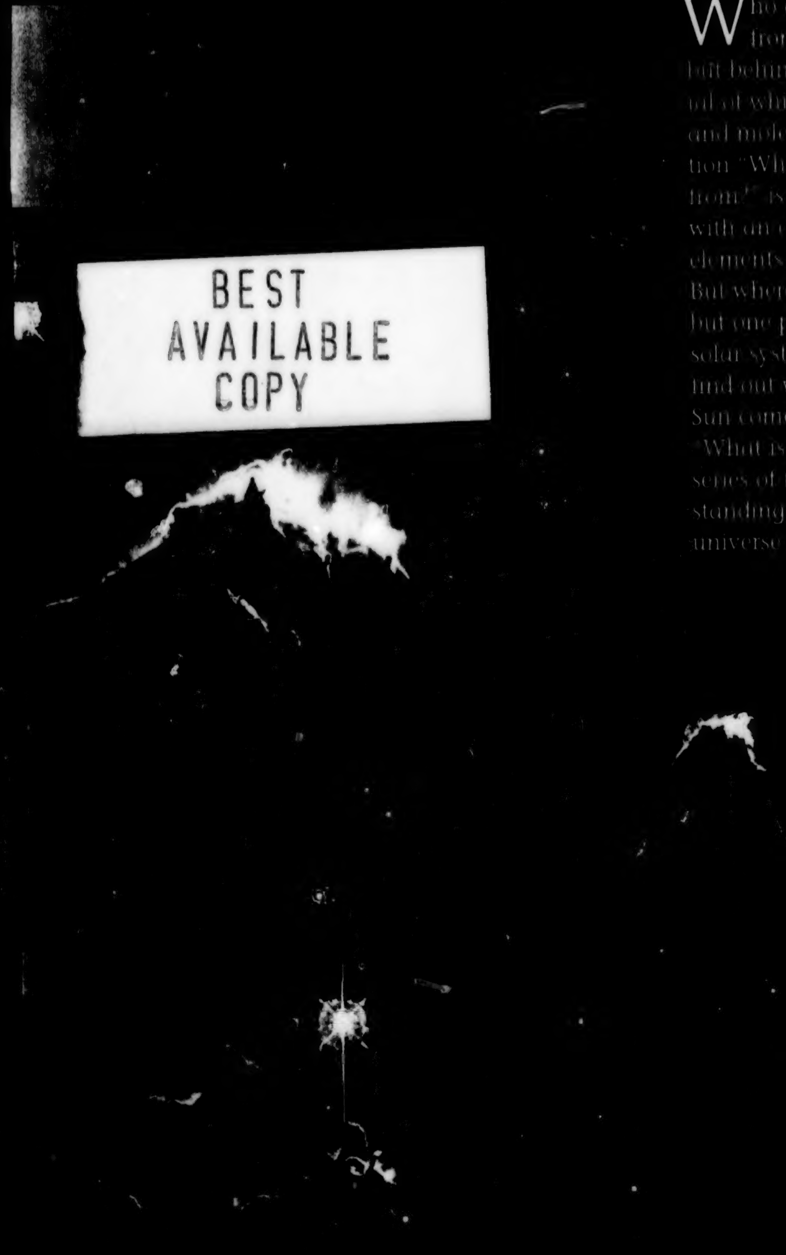
Mission:

- Launch: August 1997
- Launch Vehicle: Delta II
- Primary Mission: Observe energetic particles within the solar system
- Mission Lifetime: Two years with a five year goal

Spacecraft:

- Mass: 785 kg (includes 195 kg fuel)
- Structure: Two octagonal decks, 1.6 m across, 1.0 m high
- Propulsion: Hydrazine fuel for insertion and maintenance in orbit
- Power: 443 W, four fixed solar arrays
- Attitude Subsystem: Spinning spacecraft (5 rpm), spin axis Earth Sun pointing
- Communication Subsystem: S-band, 7 kbps (real time), 1 Gbit (total) solid state recorders

ACE Science Investigations



"What canst thou see elsewhere which thou canst not see here? Behold the heaven and the earth and all of the elements; for of these are all things created."

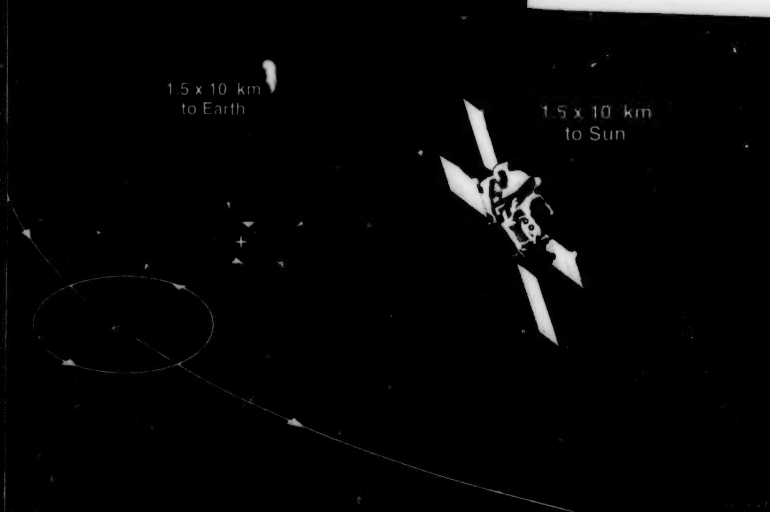
Who among us has not asked, "Where did I come from?" This question is usually one about life, but behind it are scientific questions about the material of which we are made, the elements in the atoms and molecules of our bodies. The answer to the question "Where did the matter we're made of come from?" is not so easy to find. Some could be satisfied with an answer such as "We are made of the same elements that are found on the Earth we live on." But where did that material come from? The Earth is but one planet in the solar system, and most of the solar system material is inside the Sun. How can we find out what the Sun is made of? Where did the Sun come from? One can even go further and ask, "What is the galaxy made of?" There is a whole series of related questions that are involved in understanding the cycles the matter goes through as the universe and the structures within it evolve.

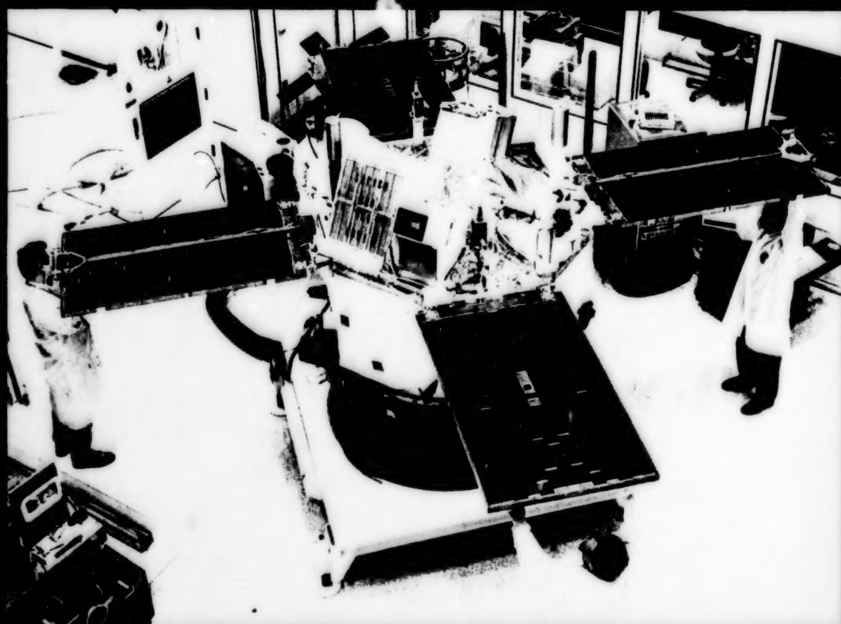
The material that Earth and the solar system are made of has been changed and rearranged during the billions of years since its creation, so measuring its complete composition, or makeup, is difficult. We have good evidence that the first elements to appear in the early universe were the lightest ones, hydrogen and helium. Most of the gas found between the stars in our Milky Way galaxy, and, we think, in other galaxies throughout the universe as well, are hydrogen and helium. We also know that the Sun is made chiefly of hydrogen and helium. We understand that stars, including our Sun, shine by the process of combining, or "burning", lighter elements into heavier ones, hydrogen into helium, and helium into carbon, and so on. In fact, in the outer layers of the Sun, we can see the light emitted by heavy elements like carbon, silicon and iron. These elements were formed by an earlier generation of stars.

Scientists have attempted to answer questions about where this matter came from and how it evolved in a variety of ways. Meteorites that have hit the Earth can be studied since, in some respects, they seem to be like the solar system when it formed. Another way to study the material is by going into space, above Earth's atmosphere, to study particles that come from the Sun. Early in this century, scientists learned that matter from space is bombarding the Earth. With the advent of space missions, we learned that it comes not only from the Sun, but also from the distant reaches of the galaxy. It has been recently discovered that some of these particles come from the gas clouds outside our solar system. The primary purpose of the Advanced Composition Explorer, ACE for short, is to study these particles. We hope to learn more about what matter is there, about its composition, where it comes from, and what it tells us about the evolution of the larger universe.

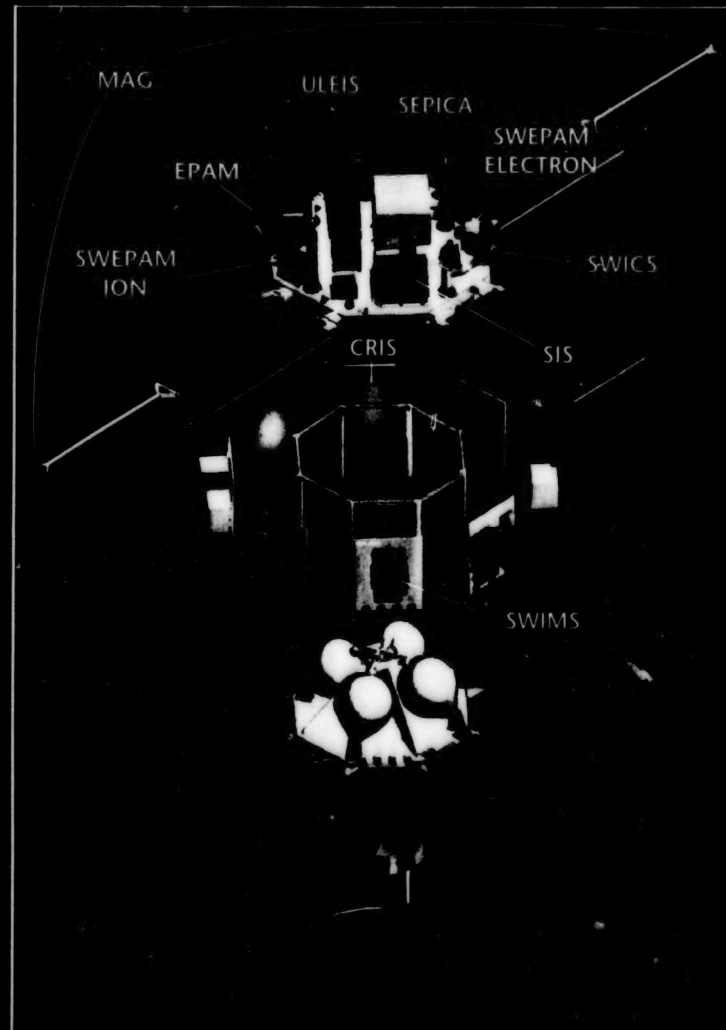
THE MISSION

ACE at L1, between the Earth and the Sun





The ACE spacecraft was built at the Applied Physics Laboratory of The Johns Hopkins University (JHU/APL).



Exploded view of the ACE spacecraft

MISSION OVERVIEW

The instruments on the ACE spacecraft are designed to sample the matter that comes near the Earth from the Sun, from the apparently (but not actually) empty space between the planets, and from the Milky Way galaxy beyond the solar system. They do so with a collecting power 10 to 1000 times greater than previous experiments. Particles are identified by type (which atom they are), by their electric charge or ionic state, and by their energy. Even very rare isotopes can be studied. The information gathered by ACE is compared with that from other missions, past and present, for a better understanding of the interaction between the Sun, the Earth, and the galaxy.

In order to measure solar particles and plasma 24 hours a day without being affected by the Earth's magnetic field, ACE will travel about 1.5 million km (about a million miles) from the Earth to the Earth-Sun **libration point, L1**. This is the point where the centripetal force and the gravitational pulls of the Earth and Sun balance. This balance keeps ACE at an ideal location for these studies. From its vantage point, 1/100 of the distance from the Earth to the Sun, ACE performs measurements over a wide range of energy. By orbiting the L1 point in a halo, ACE can follow the Earth as it revolves about the Sun, always staying between them. It avoids being in direct line with the Sun, since radio noise from the Sun would overwhelm ACE's telemetry.

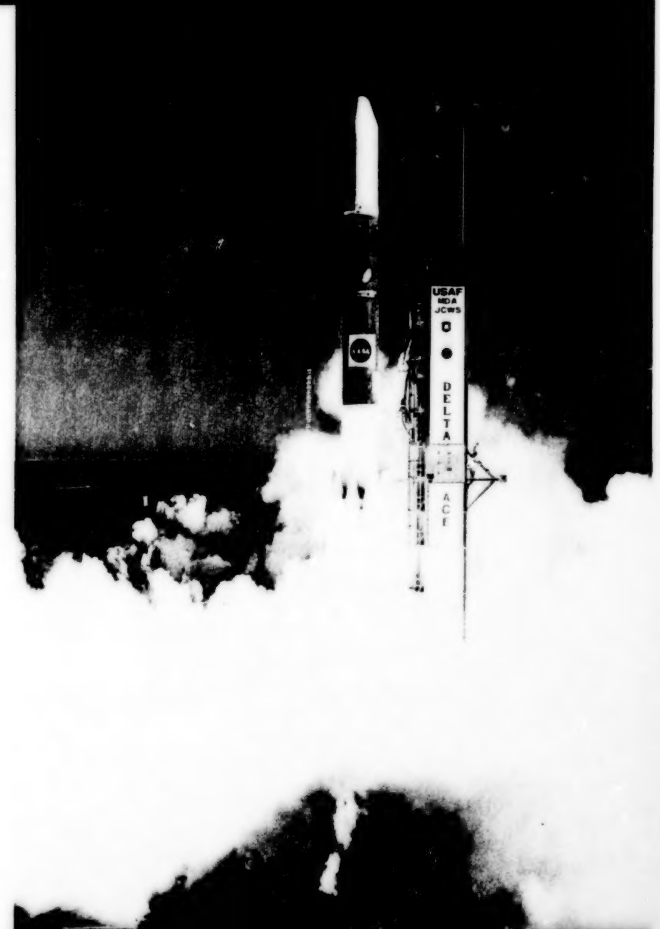
The ACE mission will last a minimum of two years. Overall NASA responsibility for the mission is in the hands of the Explorer Project Office of NASA/Goddard Space Flight Center (GSFC) in Greenbelt, MD. The lead scientific institution is the California Institute of Technology (Caltech) in Pasadena, CA. The Applied Physics Laboratory of The Johns Hopkins University (JHU/APL) in Laurel, MD was responsible for building the spacecraft.

ACE SPACECRAFT AND INSTRUMENTS

The ACE spacecraft consists of a two-deck irregular octagon, about 1.6 m (65 inches) across and about 1.0 m (40 inches) high. It spins about its axis so that one end always points toward the Sun and the other toward the Earth. It contains redundant equipment for collecting and storing data, and transmitting the data back to Earth. Data is transmitted via a highly directional parabolic dish antenna mounted on the aft (bottom) deck of the spacecraft. Four other broad-beam antennas, capable of transmitting data at lower rates, are also available if needed. Twenty four hours worth of science and housekeeping data (about 1 Gigabit), recorded on one of two solid-state recorders, will be transmitted to Earth in one three to four hour telemetry pass each day. Spacecraft attitude (the orientation of the spacecraft) is provided by a star tracker and digital Sun sensors.

Mounted to the spacecraft are eight scientific instruments which measure a variety of different particle types. Four arrays of solar cells power the spacecraft and the instruments. These arrays will provide sufficient power to allow ACE operations to continue for at least five years. Attached to two of the solar panels are booms, or long arms, for the ninth instrument, a pair of magnetometers.

Measuring a particle's type, charge, mass, energy, direction of travel, and time of arrival provide the clues needed to help determine its source and the processes that have put it where ACE could find it. These nine instruments cover an unprecedented range of particle type and energy; simultaneous measurements from these instruments are coordinated to create a comprehensive picture of the energetic particles arriving at ACE.



ACE is to be launched on a Delta II [illegible] in August 1997 from the Kennedy Space Center in Florida. Delta II is an expendable [illegible] that stands at a height of 38 m (126 ft) [illegible] 232,000 kg (511,000 lb). [illegible] most reliable [illegible]

What's New on ACE

- Coordinated measurements of three distinct samples of matter
  - Solar
  - Local interstellar
  - Galactic
- 10 - 1000 times larger collecting power
- Measures ALL solar elements, from carbon to zinc
- Determines the masses of individual atomic nuclei over a wide range of velocities

[illegible] mass ejections (CMEs), [illegible] buckle, releasing previously [illegible] material from the upper [illegible]. As a result, hot gas [illegible] solar system, impacting [illegible], and making space [illegible].

TO THE SCIENTIFIC COMMUNITY:

The mission of the ACE spacecraft is to study the composition of particles in the solar material, the local interstellar medium, and galactic matter to better understand the formation and evolution of the solar system. Each of these samples has a different history: pickup ions and anomalous cosmic rays sample the present-day interstellar medium; galactic cosmic rays provide a sample of matter from the galaxy that is thought to have been accelerated about 10 million years ago; and matter in the Sun represents an older sample of interstellar matter that has been stored in the Sun for the last 4.6 billion years. ACE is an extremely important addition to past and current studies, including balloon studies and the IMP, ISEE, Helios, Voyager, SAMPEX, SOHO, Ulysses, and WIND spacecraft.

ACE's observations will span a wide range of energy and intensities, from solar wind to galactic cosmic ray energies, and elements ranging in mass from hydrogen to zinc, during both solar active and solar quiet periods. A much more precise study is possible of the particles, including even rare isotopes, due to the vastly increased ability to collect particles and more accurately identify them. Comparative studies of these components required a coordinated approach with a suite of instruments, in order to isolate the various particle types and associate them with their acceleration process and source.

The origin and evolution of the elements can be investigated by ACE as it studies the Sun, since that is where the majority of our solar system's mass lies. ACE's precise measurements are needed to be able to determine the sources of various particles from the solar wind. Much can be learned from the comparison of this data to known information about particles from the Sun, meteorites, comets, planets, atmospheres of the planets, and the moon.

ACE scientists are testing current theories on the creation and evolution of the galaxy. The information obtained about the rare isotopes can be used to estimate the time from nucleosynthesis to the detection of a galactic cosmic ray particle by ACE. Stronger theories to explain the sequence of events in the creation of elements and isotopes can be proposed.

The observations from ACE instruments allow the exploration of a wide range of important issues, including the structure of the heliosphere, the cause of variations in it, and how the solar wind carries the magnetic field throughout it. This first extensive direct sampling and examination of solar material answers questions about the composition of matter itself.

TO THE WORLD-AT-LARGE:

In addition to the information base provided to the science community, ACE has many benefits for the rest of us.

In a partnership with NOAA, the Real-Time Solar Wind (RTSW) system on ACE functions as a "space weather station", allowing about a one-hour advance warning of magnetic storms. With proper notification, the harmful effects of these storms can be minimized, since ACE provides information about solar wind plasma, the solar magnetic field, and interm ediate and high-energy particle information to NOAA for its predictions. ACE, SOHO, and GOES work together to provide information over a wide energy range from different locations.

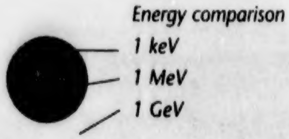
ACE is also involved in a public education partnership with the Cooperative Satellite Learning Project (CSLP). CSLP is a successful and award-winning partnership joining NASA, Allied Signal Technical Services Corporation, and schools nationwide. It is designed to motivate students of all ages into science, engineering, math, and careers in the space industry through hands-on involvement in a NASA scientific satellite mission. Through CSLP, ACE has been adopted by the Old Bridge Regional High School in Old Bridge, New Jersey. Students there are involved with, and learn from, the various stages of the ACE mission.

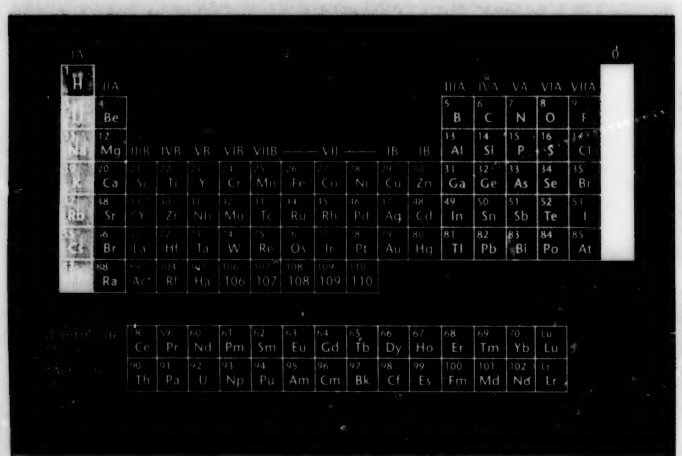
ACE was chosen as the first mission to follow NASA's Renaissance approach. "Renaissance" stands for Reusable Network Architecture for Interoperable Space Science, Analysis, Navigation, and Control Environment. This approach involves re-engineering the process by which flight projects build space communications, data, and information systems. The goal is development and operations that are cost-effective with maximum flexibility. ACE made the best use of existing hardware designs and flight spares from other NASA missions. These instruments use flight-proven technologies, requiring less development and verification time and effort.

The ACE team works with scientists, engineers and technicians from around the world, as well as around the United States, to further the interests of science. However, there are many other benefits from this teamwork. Cooperation between countries and institutions leads to more efficient solutions to mutual concerns and a freer flow of ideas. Scientists from Germany and Switzerland, in addition to California, Delaware, Illinois, Maryland, Missouri, New Hampshire, and New Mexico were involved with ACE.

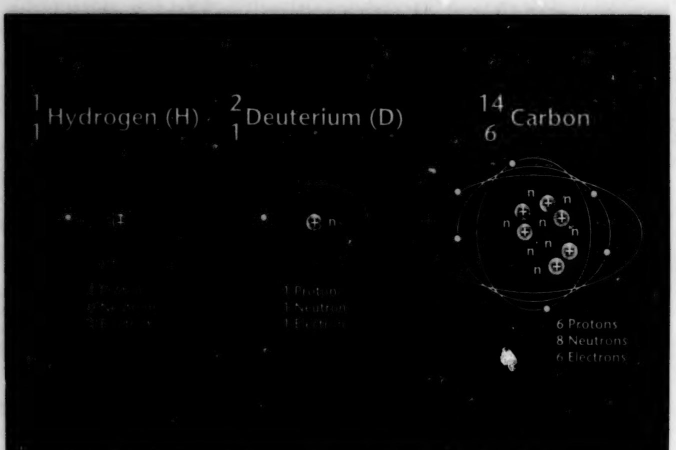
Full-scale model of ACE spacecraft built by Old Bridge Regional High School in Old Bridge, NJ

ACE's Collecting Power Compared





Periodic Table of the Elements



Hydrogen and carbon isotopes–deuterium is an isotope of hydrogen

BASIC COMPOSITION

The particles studied by ACE are **atoms** or pieces of atoms. Atoms are composed of three major building blocks: **protons** (with a positive charge), **neutrons** (with no charge), and **electrons** (with a negative charge). The **nucleus** of an atom contains the protons and neutrons, while the electrons orbit the nucleus. The number of protons determines to which **element** the atom belongs: hydrogen has one proton, carbon has six, etc.

The number of neutrons tells us which **isotope** of the element is present. The **isotope number** is the total of the number of protons plus the neutrons. Take carbon, for example, which is a very common element necessary for life, and is found in nature as diamonds and graphite. We find several different isotopes of carbon in nature.. Carbon-12 has an equal number of protons and neutrons, six of each. Carbon-14 (see isotopes diagram on the left) contains two more neutrons (eight) than carbon-12, but still has only six protons. This makes carbon-14 an isotope of carbon, but it is different from carbon-12. While carbon-12 is a stable isotope, carbon-14 is unstable, or **radioactive**. It is much less common in nature, but is found where carbon-12 is found. Because of its radioactive nature, carbon-14 is used to date archaeological artifacts.

In an atom, the number of electrons that orbit the nucleus equals the number of protons in the nucleus, thus making an atom electrically neutral. When bombarded by ultraviolet (UV) radiation or after being struck by energetic particles, atoms can lose one or more of their electrons. The positively-charged remains of these atoms are called **ions**. The number of electrons lost determines the charge state of the particle. For example, **alpha particles** are helium nuclei with a double positive charge; they have two protons and two neutrons, but no electrons.

Together with their freed electrons, the ions form a **plasma**. Plasma is a fourth state of matter, not a liquid solid, or gas. Matter in the Sun is in a plasma state. Plasma is the most common state of matter in the universe. More than 99% of all matter is plasma, so what we see on Earth is the exception. Since plasmas consist of electrically-charged particles, electric and magnetic forces affect a plasma.

When we measure the elemental, isotopic, and charge composition of ions, it helps us to understand how nature selected the particles and accelerated them to the energies at which we find them. The "composition" of the electrons is not interesting, since all electrons look the same. But the number, energy, and direction of travel are important.

ENERGETIC PARTICLES

The particles that ACE investigates have a lot of kinetic energy (they are moving very fast). An **electron volt (eV)**, is a unit of energy used to describe the total energy carried by a particle.

1 keV = 1 kilo-electron volt = 1,000 eV
— typical of dental X-rays

1 MeV = 1 mega-electron volt = 1 million eV
— typical of radioactive decay particles

1 GeV = 1 giga-electron volt = 1 billion eV
— the equivalent energy of a proton (hydrogen nucleus) at rest

The molecules in our atmosphere have energies around 0.03 eV. The Sun's plasma and Earth's **magnetosphere** (the area around Earth where its own magnetic field dominates) contain particles that are much more energetic. Protons in the magnetosphere typically have energies of 1 keV to 10 keV. And particles having still higher energies are quite common throughout the universe.

THE SUN

One of ACE's primary goals is to learn more about particles from the Sun. It contains the vast majority of all matter in our solar system. The Sun is mostly hydrogen, with some helium and smaller amounts of other elements.

The visible surface of the Sun is called the **photosphere**. The Sun's atmosphere has two transparent layers. The **chromosphere** is just above the photosphere. The **corona** is the outer part of the Sun's atmosphere. In the outer region of the corona, particles travel away from the Sun and stretch far out into space. The chromosphere and corona can only be seen during solar eclipses, or with instruments that simulate a solar eclipse.

The SOHO (Solar and Heliospheric Observatory) spacecraft is already in position at the L1 point. One of its instruments, LASCO, is a visible-light coronagraph, a device that blocks the bright light from the Sun's surface, allowing the details in the corona to be clearly seen. In the LASCO image on the right, blobs of plasma are seen emitting from the Sun. The material in these blobs of thin ionized gas is an example of what ACE studies.

NUCLEOSYNTHESIS

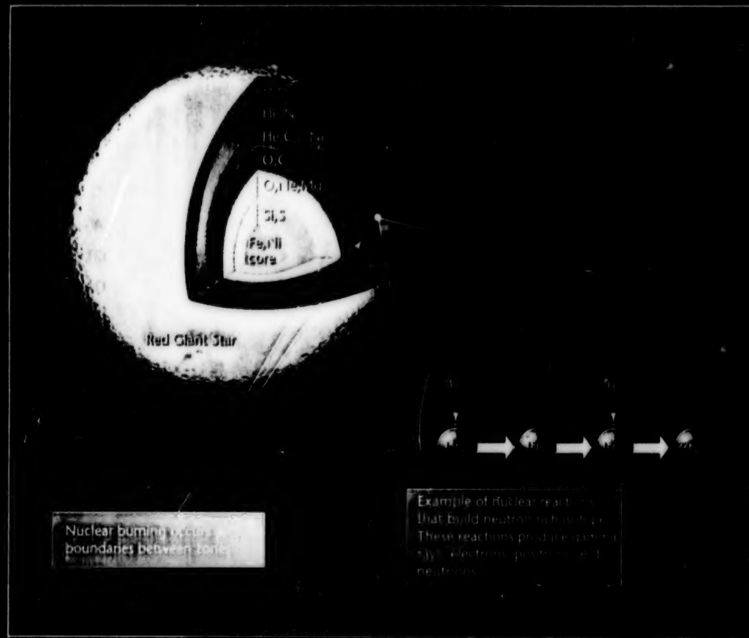
A star's energy comes from the combining of light elements into heavier elements in a process known as **fusion** or "nuclear burning". It is generally believed that most of the elements in the universe heavier than helium are created, or synthesized, in stars when lighter nuclei fuse to make heavier nuclei. The process is called **nucleosynthesis**.

Nucleosynthesis requires a high-speed collision, which can only be achieved with very high temperature. The minimum temperature required for the fusion of hydrogen is 5 million degrees. Elements with more protons in their nuclei require still higher temperatures. For instance, fusing carbon requires a temperature of about one billion degrees! Most of the heavy elements, from oxygen up through iron, are thought to be produced in stars that contain at least ten times as much matter as our Sun.

Our Sun is currently burning, or fusing, hydrogen to helium. This is the process that occurs during most of a star's lifetime. After the hydrogen in the star's core is exhausted, the star can burn helium to form progressively heavier elements, carbon and oxygen and so on, until iron and nickel are formed. Up to this point the process releases energy. The formation of elements heavier than iron and nickel requires the input of energy. **Supernova** explosions result when the cores of massive stars have exhausted their fuel supplies and burned everything into iron and nickel. The nuclei with mass heavier than nickel are thought to be formed during these explosions.

ACCELERATION

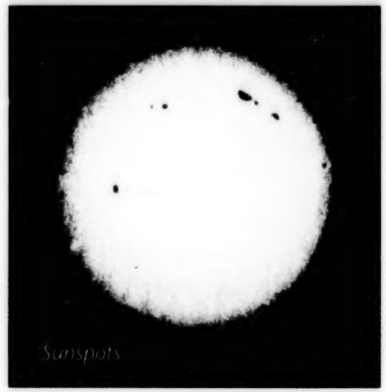
The acceleration of charged particles to extremely high energies takes place almost everywhere in the universe, very far away from us and at our front door. Particles are accelerated on the Sun, in interplanetary space, at the edge of the solar system, at the blast waves of supernova remnants, in neutron stars, and probably in black hole systems. The last two are remains from the collapse of large stars, either to the density of atomic nuclei (**neutron star**), or even further to a point such that even light cannot escape (**black hole**). Sampling a wide range of accelerated particles from local and distant sources with the ACE instruments and comparing their features provides crucial information for understanding the sources, acceleration and transport of these high-energy particles.



SOLAR ACTIVITY

The output of the Sun in all forms, light, solar wind, and energetic particles, is not constant. It varies with both time and position on the Sun. These changes are called **solar activity** and are probably reflections of changes below the Sun's surface. Scientists can study the output and how it varies to probe the workings of the Sun.

The electric currents in the Sun, as well as in planets and galaxies, generate magnetic fields. **Magnetic field lines** describe the structure of magnetic fields in three dimensions. A compass needle will always try to point along a field line. Lines close together represent strong magnetic forces and weak forces are represented as lines further apart.



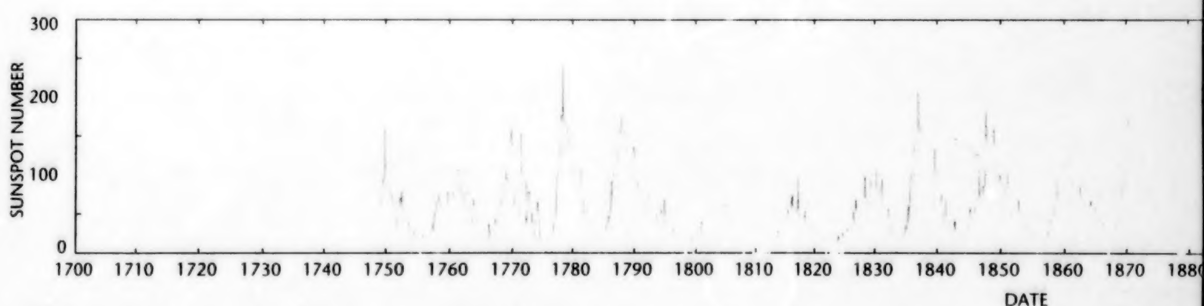
Sunspots

Sunspots, temporary disturbances in the photosphere, are the most visible advertisement of the solar magnetic field. They appear dark because temperatures are considerably lower than in surrounding areas. Sunspots occur where the magnetic field lines emerge from the inside of the Sun to form expanding loops above its surface.

A **solar flare** is an enormous explosion in the solar atmosphere. It results in sudden bursts of particle acceleration, heating of plasma to tens of millions of degrees, and the eruption of large amounts of solar mass. Flares are believed to result from the abrupt release of the energy stored in magnetic fields in the zone around sunspots.

This acceleration of solar flare particles to extremely high energies involves all the different elements in the solar atmosphere. Ions of elements such as carbon, nitrogen, oxygen, neon, magnesium, silicon, and iron, excited in this way, end up in *solar* cosmic rays, also called **solar energetic particles (SEPs)**. **Cosmic rays** are the particles and high energy light that bombard the Earth from *anywhere* beyond its atmosphere. In order to understand the acceleration processes involved and to measure the composition of the Sun, ACE instruments will study the quantity and type of these particles.

Large flares are often associated with huge ejections of mass from the Sun, although the association is not clear. These **coronal mass ejections (CMEs)** are balloon-shaped bursts of solar wind rising above the solar corona, expanding as they climb. Solar plasma is heated to tens of millions of degrees, and electrons, protons, and heavy nuclei are accelerated to near the speed of light. The super-heated electrons from CMEs move along the magnetic field lines faster than the solar wind can flow. Rearrangement of

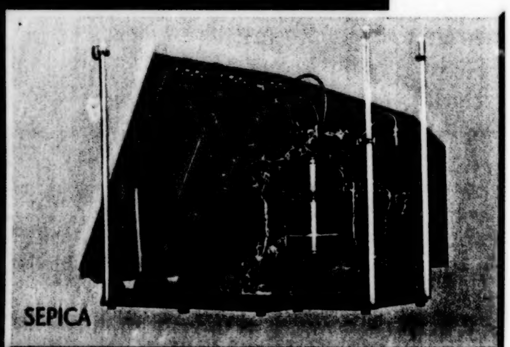


SEPICA

The Solar Energetic Particle Ionic Charge Analyzer (SEPICA) determines the ionic charge state, elemental composition, and energy spectra of energetic solar ions. This is vital information in studying the material accelerated in flares. It also allows us to learn more about element and isotope selection processes and particle acceleration on the Sun. During solar quiet times, SEPICA directly measures the charge of ACR ions (described later), including nitrogen, oxygen, and neon. It covers a range from 0.5 MeV/charge to about 5 MeV/charge for charge state composition, and up to 10 MeV/nucleon for element analysis (a **nucleon** is a particle from the nucleus, either a proton or a neutron).

SEPICA contains three multi-slit collimators that select the arrival direction of ions so that they are focused to a line in the detector. The detector system holds an electrostatic analyzer and gas-proportional counters that measure the point of impact and energy loss of the particle through a gas. The remaining energy is measured in solid-state detectors behind the proportional counter. The combination of energy loss and remaining energy allows the identification of different elements in the incoming particles. SEPICA achieves improvements of a factor of 3 in charge resolution and of a factor of 20 in collecting power over previous instruments.

SEPICA is a new instrument developed by the University of New Hampshire and the Max Planck Institute for Extraterrestrial Physics, Germany.



SEPICA

A CME event in progress. The images were taken a few minutes apart. The dark disk in the upper right corner of each frame is not the sun, but the occulting, or sun-blocking disk of the Solar Maximum Mission coronagraph used to take these images.

the magnetic field, and solar flares may result in the formation of a shock that accelerates particles ahead of the CME loop. Each CME releases up to 100 billion kg (220 billion lb) of this material, and the speed of the ejection can reach 1000 km/second (2 million mph) in some flares. Solar flares and CMEs are currently the biggest "explosions" in our solar system, occasionally approaching the power in ONE BILLION hydrogen bombs!

Solar plumes are long, feathery jets that extend from near the poles of the Sun to more than 13 million miles into space. They may be the origin of high-speed solar wind. Solar plumes expel a high-speed stream of plasma from the corona that can reach one million degrees! The base of the plume contains churning magnetic fields and solar gases. At its base, a plume is about 2500 km (1600 miles) wide.

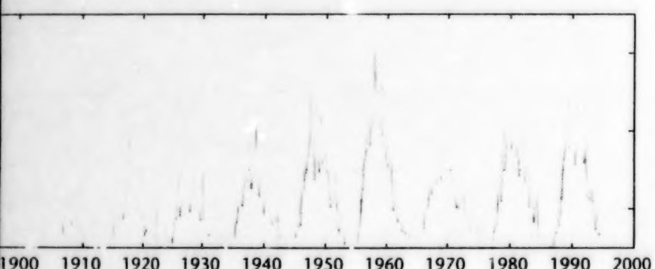
These solar events can interact and interfere with each other, creating a very complex system. Their frequency varies with time. The smaller flares tend to follow the eleven-year solar activity cycle and peak at several tens of flares per day. The largest flares usually occur only a few times during **solar maximum**, the period of maximum solar activity during the eleven-year cycle. Sunspots increase with solar maximum, and are relatively rare during solar quiet times.

ULEIS

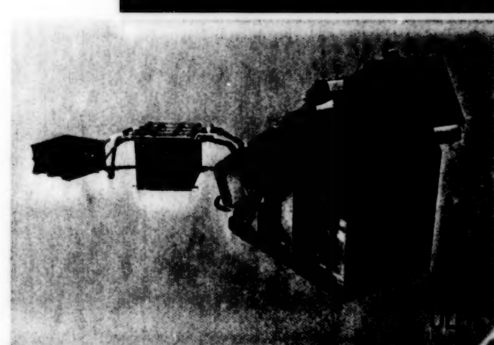
The Ultra Low Energy Isotope Spectrometer (ULEIS) measures element and isotope **fluxes** (rates of particle flow) over the range of hydrogen through nickel, from about 45 keV/nucleon to several MeV/nucleon. Studies of ultra-heavy particles, those heavier than iron, are also performed in a more limited energy range near 0.5 MeV/nucleon. ULEIS also allows the study of SEP composition and the way SEPs are energized in the solar corona.

The ULEIS instrument is a **time of flight** mass spectrometer. A time-of-flight system uses the difference in travel time through a chamber to separate ions of different masses. Along with the time-of-flight, the spectrometer simultaneously measures the energy of particles entering the telescope and stopping in one of the arrays of seven silicon solid-state detectors in the telescope. This instrument has a collecting power for solar flare isotopes more than 10 times greater than any previous instrument. ULEIS will provide more than a one thousand-fold improvement in detection for the study of CIR events, and it is a significant advance in the research of ACR isotopes (CIRs and ACRs are described later).

ULEIS is a new instrument built by University of Maryland and JHU APL.



Monthly averages of the sunspot numbers show that the number of sunspots visible on the sun waxes (during solar maximum) and wanes (solar minimum) with an approximate 11-year cycle.



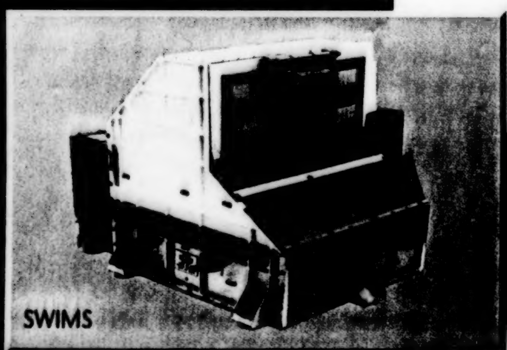
SOLAR WIND

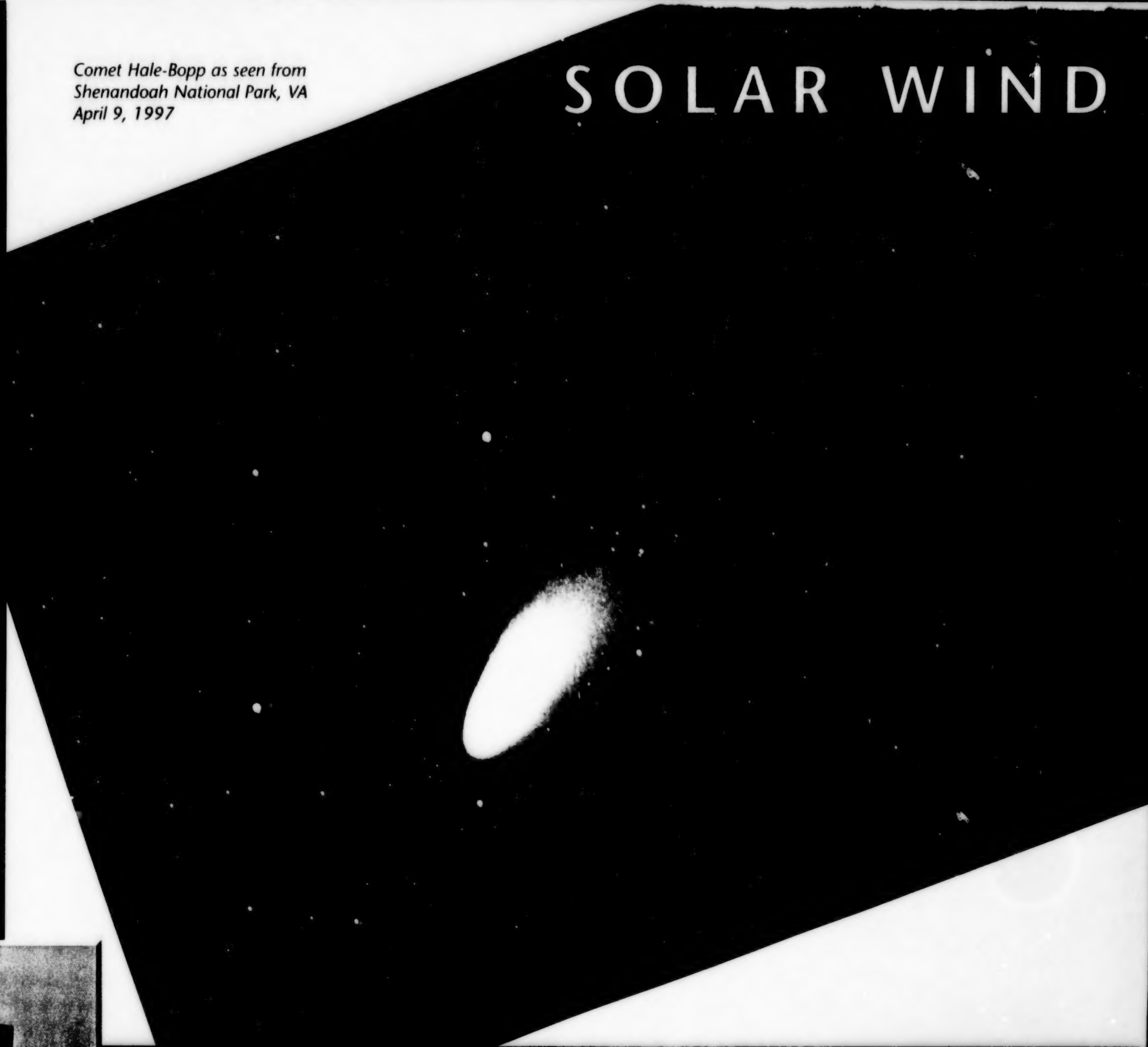
SWIMS

The Solar Wind Ion Mass Spectrometer (SWIMS) is a versatile instrument that provides solar wind composition data for all solar wind conditions. It clearly determines, every few minutes, the quantities of most of the elements and a wide range of isotopes in the solar wind. The abundances of rare isotopes are determined every few hours, providing information crucial to the understanding of pickup ions and ACRs (described later). SWIMS will extend knowledge of solar wind composition to a wide range of additional elements and isotopes.

The instrument consists of an electrostatic deflection system that selects a narrow range of energy or charge, followed by a time-of-flight High-Mass Resolution Spectrometer (HMRS). The HMRS determines the mass of a solar wind ion with high accuracy. The sensor measures speeds depending on particle mass, ranging from about 200 – 1500 km/s for helium, and from 200 to 500 km/s for iron.

SWIMS was built by the University of Maryland and the University of Bern, Switzerland. It is a copy of portions of the CELIAS experiment from the SOHO mission, adapted only slightly to optimize it for ACE.





Comet Hale-Bopp as seen from Shenandoah National Park, VA April 9, 1997

This image, taken March 7, 1996, by the Extreme-ultraviolet Imaging Telescope (EIT) on the Solar and Heliospheric Observatory (SOHO), shows an ultraviolet image of the "quiet" solar atmosphere close to the surface.

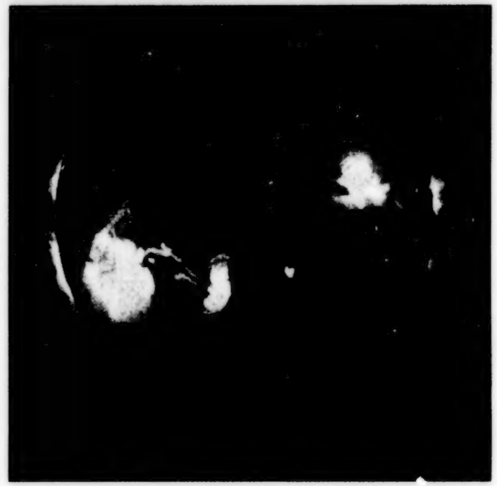
olar wind is the plasma of charged particles (protons, electrons, and heavier ionized atoms) coming out of the Sun in all directions at very high speeds — an average of about 400 km/sec, almost a million mph! It is responsible for the anti-sunward tails of comets and the shape of the magnetic fields around the planets. Solar wind can also have a measurable effect on the flight paths of spacecraft.

The composition of the solar wind reflects the composition of the solar corona, modified by solar wind processes. The exact mechanism of solar wind formation is not known. Accurately measuring its composition, as ACE does, aids in separating the effects of these processes from the original makeup of the corona.

Coronal holes are large regions in the corona that are less dense and cooler than surrounding areas. The open structure of their magnetic field allows a constant flow of high-density plasma to stream out of the holes. Solar plumes can appear in coronal holes. There is an increase in the intensity of the solar wind effects on Earth when a coronal hole faces us. Coronal holes do not last as long during solar maximum. ACE will be launched at solar minimum and continue its work through the start of solar maximum in hopes of seeing the evolution of these events.

The **heliosphere** is the immense magnetic bubble containing our solar system, solar wind, and the entire solar magnetic field. It extends well beyond the orbit of Pluto. While the density of particles in the heliosphere is very low (it's a much better vacuum than is created in a laboratory), it is full of particles of interest to ACE scientists. The **heliopause** is the name for the blurred boundary between the heliosphere and the interstellar medium outside the solar system.

As the solar wind approaches the heliopause, it



This x-ray image shows the sun as viewed by the Yohkoh satellite. A large coronal hole, extending from the Northern into the Southern Hemisphere is near the sun's center. The brightest region shows hot loops that remain after a solar flare.

slows suddenly, forming a shock wave. This **solar wind termination shock** is exceptionally good at accelerating particles.

In spite of its low density, the solar wind is strong enough to interact with the planets and their magnetic fields to shape magnetospheres. Because the ions in the solar plasma are charged, they interact with these magnetic fields, and solar wind particles are swept around planetary magnetospheres.

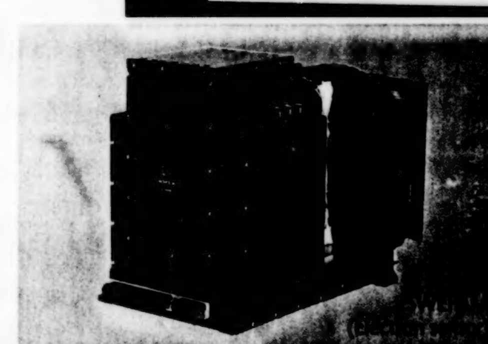
The shape of Earth's magnetosphere is the direct result of being blasted by solar wind. Solar wind compresses its sunward side to a distance of only 6 to 10 times the radius of the Earth. A supersonic shock wave is created sunward of Earth somewhat like a sonic boom. This shock wave is called the **bow shock**. Most of the solar wind particles are heated and slowed at the bow shock and detour around Earth. Solar wind drags out the night-side magnetosphere to possibly 1000 times Earth's radius; its exact length is not known. This extension of the magnetosphere is known as the **magnetotail**. Many other planets in our solar system have magnetospheres of similar, solar wind-influenced shapes.

SWEPAM

The Solar Wind Electron, Proton, and Alpha Monitor (SWEPAM) measures the solar wind plasm electron and ion fluxes as functions of direction ar energy. These data provide detailed knowledge o the solar wind conditions every minute. SWEPAM also provides real-time solar wind observations th are continuously sent to the ground for space weather purposes.

Electron and ion measurements are made wit separate sensors. The ion sensor measures particl energies between about 0.26 and 36 KeV, and th electron sensor's energy range is between 1 and 1350 eV. Both sensors use electrostatic analyzers with fan-shaped fields-of-view. The electrostatic analyzers measure the energy per charge of each particle by bending its flight path through the system. The fields-of-view are swept across all so wind directions by the rotation of the spacecraft.

SWEPAM was built by the Los Alamos Nationa Laboratory in New Mexico. It is built from the spare solar wind electron and ion analyzers from t Ulysses mission, with selective modifications and improvements.



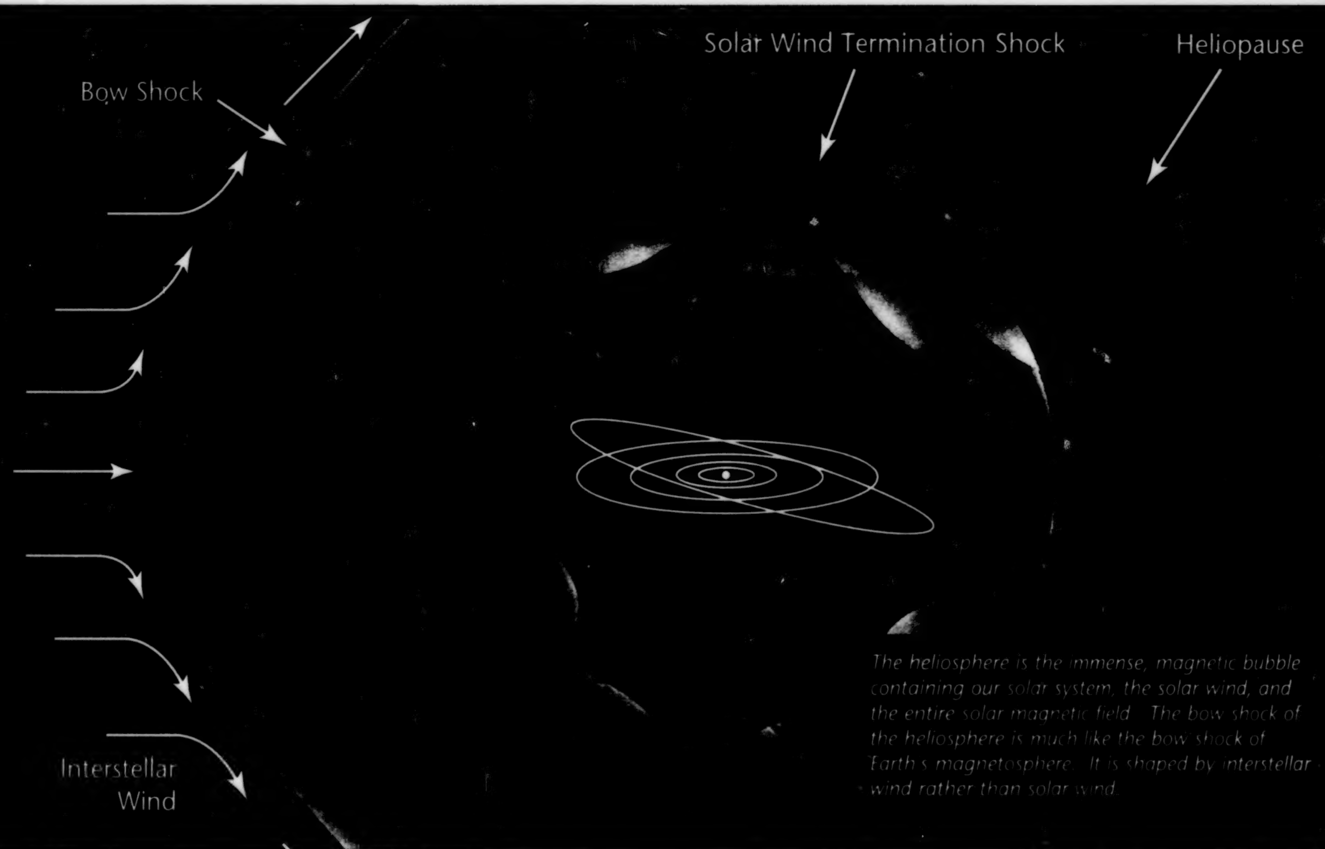
THE HELIOSPHERE

EPAM

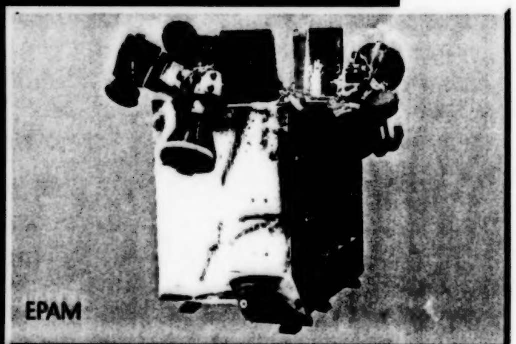
Knowledge of the fluxes and energy of high-energy protons, alpha particles, and electrons is essential in understanding the dynamic behavior of solar flare, CIR and ESP events. These measurements are made by EPAM, the Electron, Proton, and Alpha Monitor. This instrument provides information that can reflect changes in both coronal and interplanetary magnetic fields, and information on solar flares. EPAM covers the range of energies from 30 keV/nucleon up to 4 MeV/nucleon. It measures the composition of elements up through iron.

EPAM includes five telescopes of three different types: Two Low Energy Foil Spectrometers (LEFS) measure the flux and direction of electrons above 30 keV. Two Low Energy Magnetic Spectrometers (LEMS) measure the flux and direction of ions greater than 30 keV. And the Composition Aperture (CA) measures the composition of the ions. Solid-state detectors on each telescope analyze the energy of the incoming particles. These telescopes use the spin of the spacecraft to sweep the full sky.

The EPAM instrument was built by JHU/APL with Dr. L.J. Lanzerotti of Lucent Technologies as Principal Investigator. It is the flight spare of the HI-SCALE instrument from the Ulysses spacecraft.



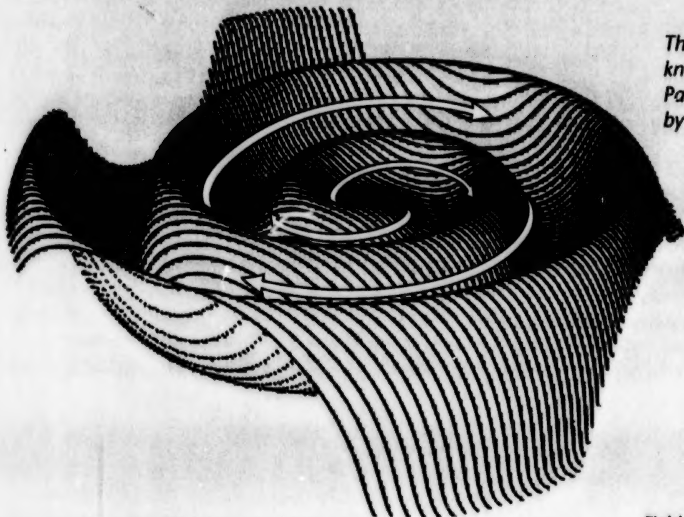
The heliosphere is the immense, magnetic bubble containing our solar system, the solar wind, and the entire solar magnetic field. The bow shock of the heliosphere is much like the bow shock of Earth's magnetosphere. It is shaped by interstellar wind rather than solar wind.



The electric currents in the Sun generate a complex magnetic field which extends out into interplanetary space to form the interplanetary magnetic field. In space, charged particles tend to become attached to magnetic field lines, spiraling around them while sliding along them, like beads on a wire. Because of this attachment, the behavior of energetic particles in space is dictated by the structure of field lines. Magnetic field lines are frozen into plasmas and move as the plasmas move.

As the Sun's magnetic field is carried out through the solar system by the solar wind, the Sun is rotating. Its rotation winds up the magnetic field into a large rotating spiral, known as the **Parker spiral**, named after the scientist who first described it.

The magnetic field is primarily directed outward from the Sun in one of its hemispheres, and inward in the other. This causes opposite magnetic field directions in the Parker spiral. The thin layer between the different field directions is described as the neutral current sheet. Since this dividing line between the

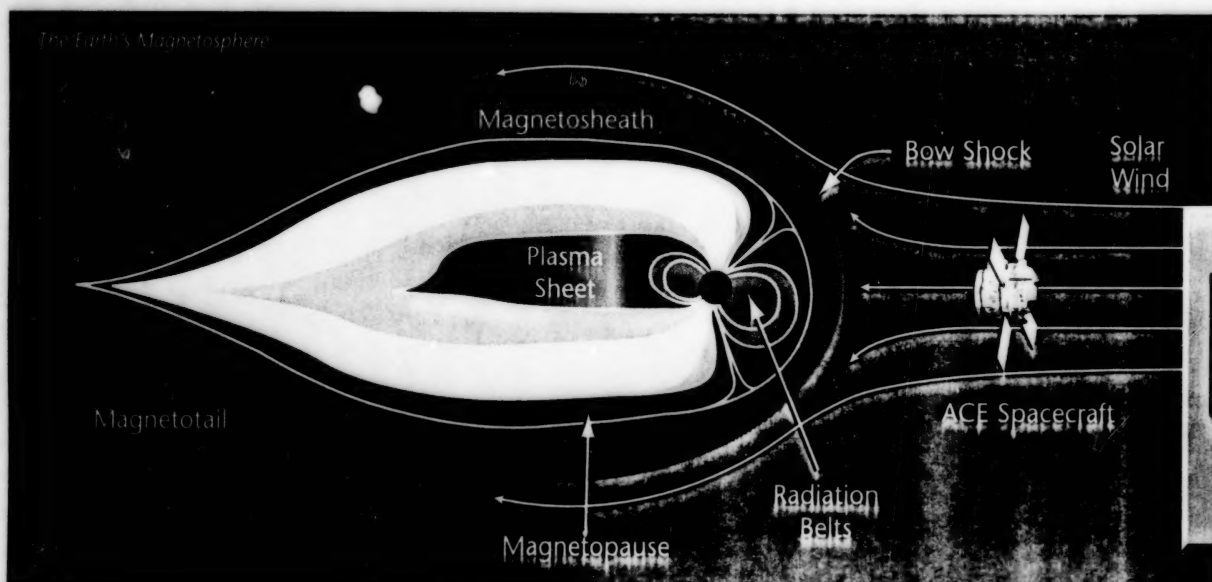


The neutral current sheet, sometimes known as the "ballerina skirt". The Parker spiral magnetic field is indicated by the arrows.

Field lines show the magnetic field around a bar magnet.

outward and inward field directions is not exactly on the solar equator, the rotation of the Sun causes the current sheet to become "wavy", and this waviness is carried out interplanetary space by the solar wind.

In addition, every eleven years the entire magnetic field of the Sun "flips"- the north magnetic pole of the Sun becomes the south, and vice versa. The flip takes place at solar maximum. The last maximum was in 1989.

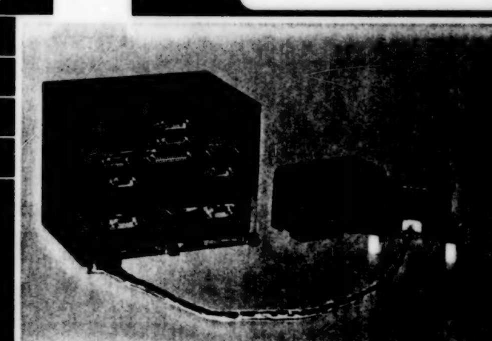


MAG

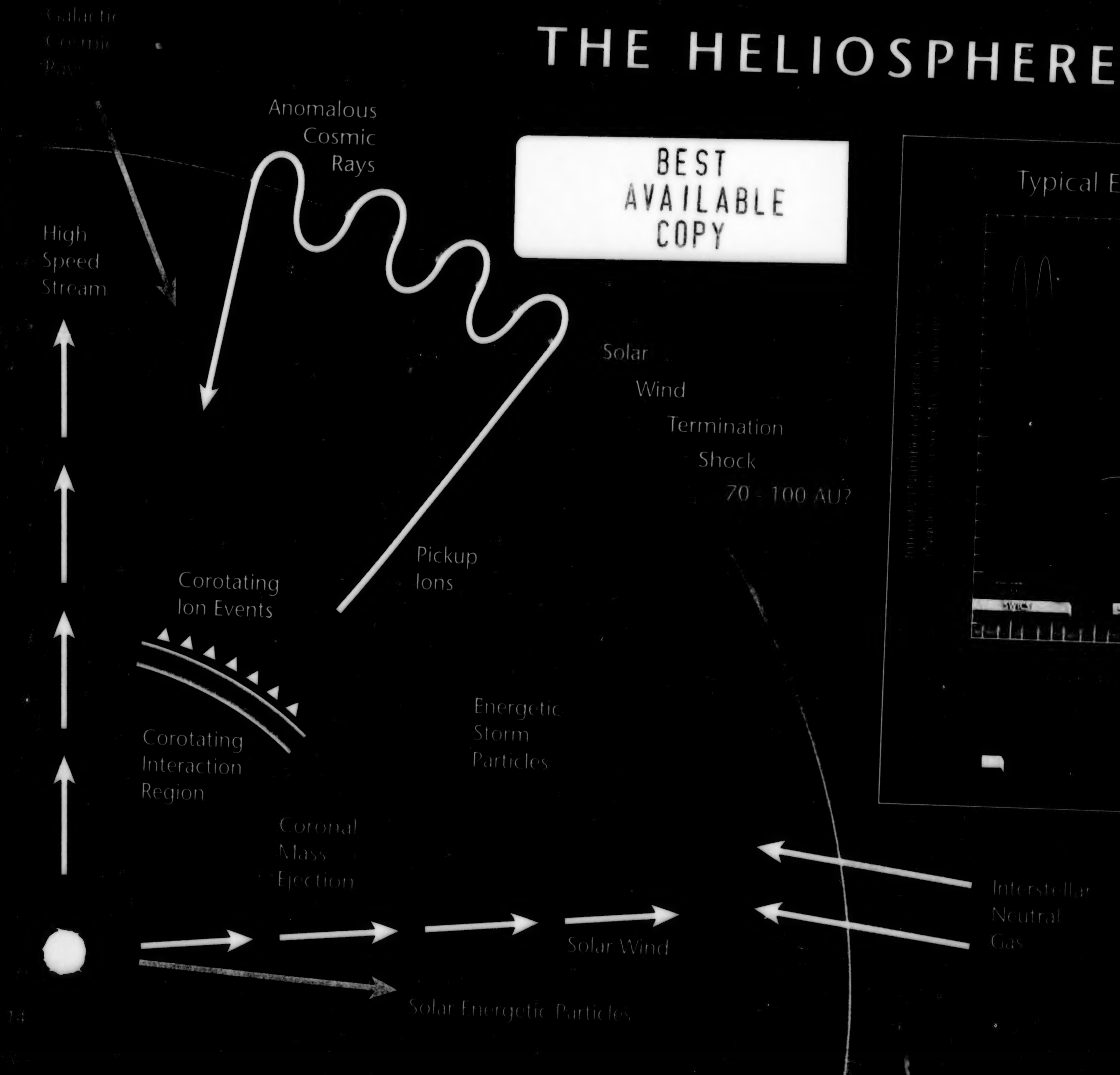
Precise examination of the interplanetary and solar magnetic fields and their dynamics provides essential supporting information for the other ACE instruments. The two magnetometers (MAG) on ACE detect and measure the magnetic fields in the vicinity of the spacecraft. As the magnetometers sweep through a field when the spacecraft rotates, electrical signals are produced which are proportional to the strength and direction of the field.

MAG consists of two wide-range triaxial magnetometers. Triaxial means that all three axes (x, y, and z) of the magnetic field are measured. This allows for the determination of its exact direction. The magnetometers are mounted out from the spacecraft on separate long booms to reduce the effects of any magnetics from the spacecraft and instruments. MAG measures the strength and direction of the interplanetary magnetic field 30 times per second and can calculate any pattern of variations in it.

The scientific institutions involved in building MAG were the Bartol Research Institute in Newark, DE, and GSFC. It is a flight spare from the WIND mission.



THE HELIOSPHERE



he solar wind near our Sun's surface contains alternating streams of high and low speed. These streams **corotate** with the Sun; that is, they rotate along with it. The high-speed streams originate in coronal holes and extend toward the solar poles; the low-speed streams come from near the equator. ACE sees mostly the low-speed solar wind due to its location, but can observe the compositional differences between the high- and low-speed wind when coronal holes extend down near the equator. One objective of ACE will be to understand how the high- and low-speed winds are accelerated.

With increasing distance from the Sun, the high-speed streams overtake the slower plasma producing **corotating interaction regions (CIRs)** on their leading edges. CIRs are bounded by two shocks at the front and rear edges called the **forward** and **reverse shocks**. At these shocks, the density, pressure, and magnetic field strength are all higher. These regions are quite effective as energetic particle accelerators. When ions that have been accelerated at a CIR are observed, they are called **corotating ion events**.

Energetic storm particles (ESPs), accelerated by shocks associated with solar flares and CMEs, are another example of interplanetary acceleration. ACE will be able to directly compare the composition of ESPs with that of the solar wind to test shock acceleration theories.

ACE will study the many different types of speeding (energetic) particles in the solar system. These include the solar wind, high-speed streams (high-speed solar wind), coronal mass ejections (CMEs), and solar energetic particles (SEPs) coming from the sun, energetic storm particles (ESPs) and corotating ion events (CIRs) from interplanetary space, anomalous cosmic rays (ACRs) from the edge of the solar system (the solar wind termination shock), interstellar neutral gas and the pickup ions which originate in the gas right outside the solar system (the very local interstellar medium), and galactic cosmic rays (GCRs) from the far reaches of the galaxy. These energetic particles are described in this brochure.

The smaller figure (opposite page) is an illustration of the number of particles observed (for a standard area and energy interval) versus energy, for the many different energetic particles observed by ACE. Most of these particle types actually vary with time by large factors. So these "specta" are not really accurate for any particular element; it is just an example.

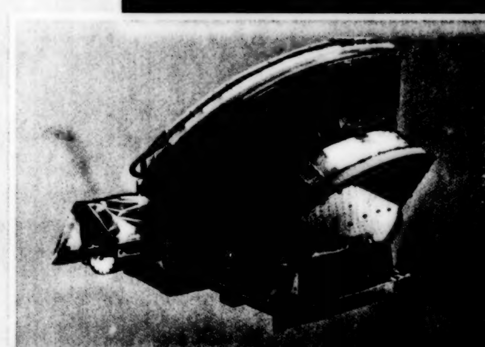
In the larger figure (opposite page), the color used for each type of particle or event matches the color of its corresponding energy population, shown in the graph on the right.

SWICS

The Solar Wind Ion Composition Spectrometer (SWICS) determines not only the charge of ions, but also the temperature and speeds of all the major solar wind ions. SWICS covers solar wind speeds ranging from 145 km/s (protons) to 1532 km/s (iron). The information recovered tells scientists about the nature of not only the solar wind, but also of solar flares, ESPs, CIRs, and pickup ions (descibed later).

SWICS combines an electrostatic analyzer with post-acceleration, followed by a time-of-flight and energy measurement. Post-acceleration means that after the electrostatic analyzer, the particle is re-accelerated to determine its mass.

SWICS was built by University of Maryland and the University of Bern, Switzerland. The instrument is the same as one fully developed, designed, and tested during the Ulysses mission. A flight spare from that mission was used for ACE.

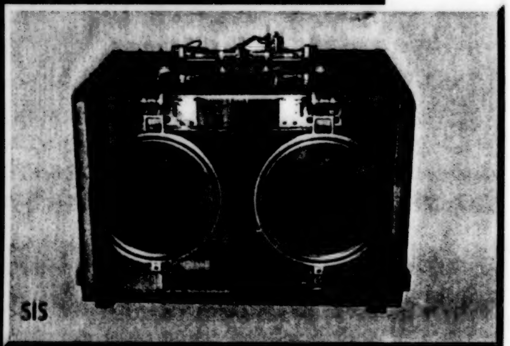


SIS

The Solar Isotope Spectrometer (SIS) will measure the elemental and isotopic composition of matter from helium to zinc in the energy range from about 10 to 100 MeV/nucleon. During solar active periods the flux of solar energetic particles can suddenly increase by a factor of 10,000 or more, providing an opportunity for SIS to measure the composition of solar material. The SIS detector system consists of two identical particle telescopes. Each telescope has a pair of silicon-strip detectors to sense the **trajectory** (path) of incident nuclei, followed by a stack of large-area silicon solid-state detectors that measure the energy lost by nuclei as they slow and stop. By combining these measurements it is possible to compute the nuclear charge, mass, and kinetic energy of each incident particle.

An innovative feature in SIS is the use of custom low-power VLSI (very large-scale integration) circuitry to measure signals from the 512 strips of the trajectory system. This circuitry, which uses only about 1/10 the power of previous instrumentation, enables measurements of both position and energy loss for multiple particles that may arrive within a few microseconds of each other during large solar particle events. The collecting power of SIS is about 100 times greater than that of previous solar particle isotope spectrometers.

SIS is a new instrument developed by Caltech, GSFC, and NASA's Jet Propulsion Laboratory at Caltech (JPL).



LOCAL INTERSTELLAR MEDIUM

The relative numbers of different isotopes found in the galaxy are established by the life cycle of massive stars. Their formation, evolution and explosion results in the creation of many of the heavier isotopes ACE finds in space. The process follows; see the figure below.

In a part of the galaxy where the composition of the interstellar gas is much like that of our own solar system (a), a cloud of gas collapses under the influence of its own gravity, and creates a new star (b). Inside the star (c), fusion converts some of the original hydrogen and helium into particles like carbon-12 and oxygen-16. At the same time, the carbon, nitrogen, and oxygen nuclei that were originally present in the stellar fuel are converted into heavier, neutron-rich nuclei, like neon-22 and magnesium-25.

When this quiescent burning has exhausted all of the nuclear fuel in the core of the star, the star explodes as a supernova (d). The shock wave generated by the explosion synthesizes additional heavy nuclei and ejects most of the products of nucleosynthesis back into the interstellar gas.

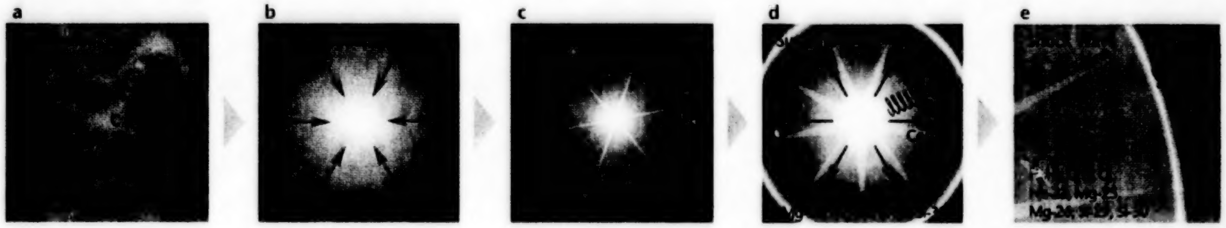
Repetition of these events in each generation of stars steadily enriches the interstellar gas in carbon, nitrogen, and oxygen, and in heavy nuclei with an excess of neutrons.

Some of the nuclei in the gas are accelerated to cosmic ray speeds, possibly by the shock waves from supernovae (e). Cosmic ray acceleration could also occur directly as the supernova is ejecting matter into interstellar space, as in (d).

While interstellar plasma is kept outside the heliosphere by an interplanetary magnetic field, the interstellar *neutral* gas flows through the solar system like an interstellar wind, at a speed of 25 km/sec. When closer to the Sun, these atoms undergo the loss of one electron in **photo-ionization** or by **charge exchange**. Photo-ionization is when an electron is knocked off by a solar UV photon, and charge exchange involves giving up an electron to an ionized solar wind atom. Once these particles are charged, the Sun's magnetic field picks them up and carries them outward to the solar wind termination shock. They are called **pickup ions** during this part of their trip. By measuring the distribution of these pickup ions, ACE will determine the composition, flow and temperature of the neighbor-ing interstellar gas.

The ions repeatedly collide with the termination shock, gaining energy in the process. This continues until they escape from the shock and diffuse toward the inner heliosphere. Those that are accelerated are then known as **anomalous cosmic rays (ACRs)**.

It is not certain exactly which particles are accelerated at the solar wind termination shock; ACE will tell us more.



Nucleosynthesis in massive stars

GALACTIC COSMIC RAYS

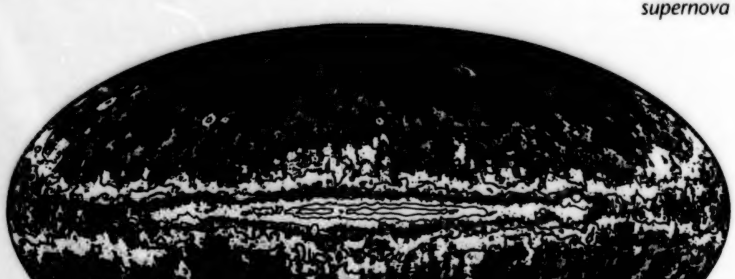
alactic cosmic rays (GCRs) come from outside the solar system but generally from within our galaxy. GCRs are atomic nuclei from which all of the surrounding electrons have been stripped away during their high-speed passage through the galaxy. They have probably been accelerated within the last few million years, and have traveled many times across the galaxy, trapped by the galactic magnetic field. As they travel through the very thin gas of interstellar space, some of the GCRs interact and emit gamma rays, which is how we know that they pass through the Milky Way and other galaxies.

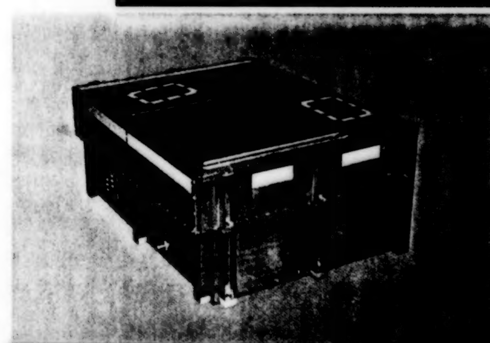
GCRs have been accelerated to nearly the speed of light, probably by supernova remnants. But exactly which particles the supernova remnants accelerate is one of the questions that ACE will try to answer.

The *elemental* makeup of GCRs has been studied in detail by earlier experiments, and is very similar to the composition of the Earth and solar system. But previous studies of the composition of the *isotopes* in GCRs may indicate that the seed population for GCRs is neither the interstellar gas nor the shards of giant stars that went supernova. ACE will perform a detailed survey of the isotopic makeup of GCRs, which should shed light on this intriguing puzzle.

Included in the cosmic rays are a number of radioactive nuclei whose numbers decrease over time. As in the carbon-14 dating technique, measurements of these nuclei by ACE will be used to determine how long it has been since cosmic ray material was synthesized in the galactic magnetic field before leaking out into the vast void between the galaxies. These nuclei are called "cosmic ray clocks".

This false color composite picture of the bright supernova remnant SN1006 (above) was taken by the ASCA satellite. The expanding gas from the star collided into the surrounding material. The collision generated a violent shock, which produced x-ray light. The bright regions in the picture show the locations of this shock along the rim of the remnant. The energy spectrum produced in SN1006 provides the first clear link between particle acceleration at supernova shock fronts and high-energy cosmic rays.





EGRET gamma ray all-sky survey - above 100 MeV. Some GCRs interact with the interstellar medium and produce gamma rays.

Astronaut Edwin Aldrin walks on the lunar surface near the leg of the Apollo 11 Lunar Module.

Magnetic storms produce many noticeable effects on and near the Earth, including the northern and southern lights. This photograph of the Aurora australis *(Southern lights) is from Spacelab 3.*

The Sun's activity causes large changes in the Sun's plasma and energetic particle populations, and these changes are responsible for the "space weather" that affects Earth. Space weather can impact the upper atmosphere and may influence long-term climate trends. The effects are related to CMEs, SEPs, and coronal holes, the source of high-speed streams. The largest storms occur when a fast CME hits Earth shortly after its shock arrives.

Geomagnetic storms (magnetic storms on Earth due to solar activity) produce the awe-inspiring *Aurora borealis* and *Aurora australis* — the Northern and Southern lights. However, they can also cause a variety of highly undesirable consequences. Electrical current surges in power lines, interference in the broadcast of radio, television, and telephone signals, and problems with defense communications are all associated with magnetic storms. Odd behavior in air and marine navigation instruments has been observed, and a compass anywhere on Earth is certainly affected. These storms are known to alter the atmospheric ozone layer. Even increased pipeline corrosion has been attributed to them.

Major solar activity is a very serious concern in space flight. Communications may be disrupted. Large solar disturbances heat the upper atmosphere, causing it to expand and create increased drag on spacecraft in low orbits, shortening their orbital lifetime. Spacecraft could potentially tumble and burn up in the atmosphere. Intense SEP events contain very high levels of radiation, more than a million times the normal daily dose of a human on Earth. Radiation sickness can result when humans are outside the protective magnetosphere of the Earth, as in missions to the moon and to Mars.

High-energy solar protons can produce increased radiation in the atmosphere at altitudes where supersonic aircraft fly. This is especially true for flights over the north and south magnetic poles, areas unprotected by the Earth's magnetic field, where the radiation has direct access to the atmosphere. To reduce the risk to aircraft crews and passengers, and reduce risk to the aircraft, routine forecasts and alerts are sent through the Federal Aviation Administration so that a flight in potential danger can consider what course of action to take to minimize radiation exposure. The National Oceanic and Atmospheric Administration (NOAA) forecasts high-speed solar wind and solar particle events.

The continuous broadcast of solar wind, magnetic field, and SEP data from ACE is expected to allow very accurate forecasts of major activity up to one hour beforehand. In particular, ACE will detect large CMEs and their associated shocks before they reach Earth, just like weather stations on Earth measure major storms as they move across the continent. This will remove much of the guesswork from space weather forecasts and should represent a major advance in NOAA's forecast ability, as well as furthering our understanding of the scientific processes involved.

DATA ANALYSIS AND DELIVERY

The ACE Science Center at Caltech obtains the spacecraft telemetry from the ACE Flight Operations team and GSFC. It then produces a data set that is more appropriate for science data processing. The Center makes interesting plots available to scientists around the world and takes advantage of emerging World Wide Web technology, making it possible for users to request specific information as needed.

Real-Time Solar Wind (RTSW)

Geomagnetic storms are a natural hazard that NOAA forecasts for the benefit of the public, as it does hurricanes, and ground tornadoes. The location of ACE enables it to provide about one-hour advance warning of impending major geomagnetic activity.

The ground system developed by NOAA receives the data broadcast by ACE in real-time (as it is happening). This system also includes the Communications Research Laboratory in Japan, the US Air Force Satellite Control Network, and NASA ground stations. A subset of data is sent from SWEPAM, EPAM, MAG, and SIS during the time that ACE is not transmitting its full telemetry.

For about 21 of 24 hours per day, ACE broadcasts the real-time solar wind data. The data is received by the ground stations around the world and sent directly to NOAA. During the three hours per day that NASA ground stations are receiving full ACE telemetry, NOAA receives a copy of the data. This gives them 24 hour per day forecasting. NOAA processes the data at its Space Environment Center in Boulder, CO, which issues alerts of any potential geomagnetic problems.

CONCLUSIONS

World Wide Web Access

ACE home page at NASA/GSFC:
http://www.gsfc.nasa.gov/ace/ace.html

ACE home page at Caltech:
http://www.srl.caltech.edu/ACE

CSTP home page:
http://joy.gsfc.nasa.gov/CSTP/home.html

NOAA Space Environment Center's "Today's Space Weather":
http://www.sec.noaa.gov/today.html

NASA home page:
http://www.nasa.gov

Cosmic and Heliospheric Learning Center at NASA/GSFC:
http://helios.gsfc.nasa.gov

Science has barely scratched the surface in examining the actual source of the particles traveling through space around us. The mix of particles that ACE will measure is the result of a complex history. The ability of the ACE's nine instruments to measure a wide range of particle types and energies at the same time and location, is what will enable scientists to separate the many processes the matter has undergone on its way to ACE.

The prime purpose of ACE is to study the composition of several distinct sources of matter, the Sun and solar system, the local interstellar space, and the galaxy as a whole. This, in turn, will lead us to a better understanding of the origin of the elements, and the subsequent evolutionary processing of matter (how it has changed since it was created). Along the way, ACE will learn more about particle acceleration and transport in the universe, information needed to separate the changes in composition during the particles' travel. Learning the differences in composition between the solar wind and the Sun will help answer questions about how the solar corona is formed and how solar wind is accelerated. All of these interesting problems are part of the larger question "Where did we come from?" ACE is one piece of the enormous puzzle.

As new information becomes available, from both spacecraft and Earth-based instruments, the picture becomes clearer. Theories are upheld or upset, and new theories take their place. ACE provides an abundance of information to further our understanding of the way our solar system, galaxy, and universe were created and how they continue to evolve.

This is a ground-based image of the entire Crab nebula, the remnants of a supernova explosion over 900 years ago. The green, yellow and red filaments toward the edges are the remains of the star that were ejected into space by the explosion. The blue glow in the inner part is light emitted by energetic electrons as they spiral through the Crab's magnetic field.

NASA Headquarters
Mr. Louis Demas
— *Senior Program Executive*
Dr. W. Vernon Jones
— *ACE Program Scientist*

NASA Goddard Space Flight Center (NASA/GSFC) Explorer Project Office
Overall project management
Mr. Donald Margolies
— *ACE Mission Manager*
Mr. John Thurber
— *ACE Observatory Manager*
Mr. John Laudadio
— *ACE Instrument Manager*
Mr. William Cross
— *ACE Systems Manager*
Mr. Francis Snow
— *ACE Ground System Project Manager*
Ms. Lynn Clark
— *Contracting Officer*
Science management
Dr. Jonathan Ormes
— *ACE Project Scientist*
Dr. Eric Christian
— *Deputy Project Scientist*

California Institute of Technology (Caltech) Space Radiation Laboratory
Science payload management
Dr. Edward Stone
— *Principal Investigator*
Dr. Richard Mewaldt
— *ACE Mission Scientist*
Mr. Allan Frandsen
— *Payload Manager*
Dr. Gerald Murphy
— *Payload Systems Engineer*
Mr. Howard Eyerly
— *Payload Product Assurance Engineer*
Ms. Midge Breslof
— *ACE Contracts Administrator*
ACE Science Center
Dr. Thomas Garrard
— *ACE Science Center Manager*

The Johns Hopkins University Applied Physics Laboratory (JHU/APL)
Spacecraft development
Observatory integration and test
Ms. Mary Chiu
— *Program Manager*
Ms. Judi von Mehlem
— *Spacecraft Systems Engineer*

Principal Investigator:
Dr. Edward Stone — *Caltech/JPL*

Project Scientist:
Dr. Jonathan Ormes — *NASA/GSFC*

Co-Investigators:
Dr. Walter Binns — *Washington University*
Dr. Peter Bochsler — *University of Bern*
Dr. Leonard Burlaga — *NASA GSFC*
Dr. Alan Cummings — *Caltech*
Dr. William Feldman
— *Los Alamos National Laboratory*
Dr. Thomas Garrard — *Caltech*
Dr. Johannes Geiss — *University of Bern*
Dr. George Gloeckler
— *University of Maryland*
Dr. Robert Gold — *JHU/APL*
Dr. Dieter Hovestadt — *Max Planck Institute for Extraterrestrial Physics*
Dr. Berndt Klecker — *Max Planck Institute for Extraterrestrial Physics*
Dr. Stamatios Krimigis — *JHU/APL*
Dr. Glenn Mason — *University of Maryland*
Dr. David McComas
— *Los Alamos National Laboratory*
Dr. Richard Mewaldt — *Caltech*
Dr. Eberhard Möbius
— *University of New Hampshire*
Dr. Norman Ness — *University of Delaware*
Dr. John Simpson — *University of Chicago*
Dr. Tycho von Rosenvinge — *NASA GSFC*
Dr. Mark Wiedenbeck — *Caltech/JPL*

- E. Christian, NASA/GSFC
  ACE model photograph
- F. Espenak, NASA/GSFC
  Comet Hale-Bopp photograph
- C. Fichtel and the EGRET Instrument Science Team
  EGRET gamma-ray all-sky survey
- GSFC Graphics Department
  All additional graphics
- D. Hathaway, NASA/MSFC
  Sunspot cycle diagram
- J. Hester and P. Scowen, AZ State Univ. and NASA
  Eagle nebula image
- High Altitude Observatory, National Center for Atmospheric Research (NCAR), Boulder, Colorado - NCAR is sponsored by the National Science Foundation
  Images of CME event in progress
- J. Jokipii, Univ. of AZ
  Neutral current sheet image
- JHU/APL
  ACE Logo
  ACE Science Investigations artwork
  ACE spacecraft photograph
  Exploded ACE diagram
  ACE at L1 artwork
  All individual instrument photographs
- R. Mewaldt, E. Stone, and M. Wiedenbeck
  Galactic evolution images
- McDonnell Douglas Corporation
  Delta II rocket photograph
- NASA Archives
  Sun image with sunspots
  Photograph of astronaut Edwin Aldrin
  Crab nebula image
- R. Overmyer/NASA
  Aurora australis *image*
- R. Petre and E. Gotthelf, GSFC NASA
  SN1006 image
- SOHO/LASCO and SOHO/EIT consortia - SOHO is a project of international cooperation between ESA and NASA.
  SOHO/LASCO coronagraph image
  Image of "quiet" solar atmosphere
- SOON Telescope, Holloman AFB, NOAA
  CME image
- Yohkoh mission of ISAS, Japan - The x-ray telescope was prepared by the Lockheed Palo Alto Research Laboratory, the National Astronomical Observatory of Japan, and the University of Tokyo, with the support of NASA and ISAS.
  Sun image with coronal holes

ADVANCED COMPOSITION EXPLORER

ACE
NASA

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NASA

Goddard Space Flight Center

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